

The recovery of the Antarctic ozone hole

P. Newman, E. Nash, S. R. Kawa, A. R. Douglass

Introduction

How do we define the size of the Antarctic ozone hole?

What affects the size?

Zeroth order answer: chlorine and bromine

First order answer: temperature

Can we model size variations?

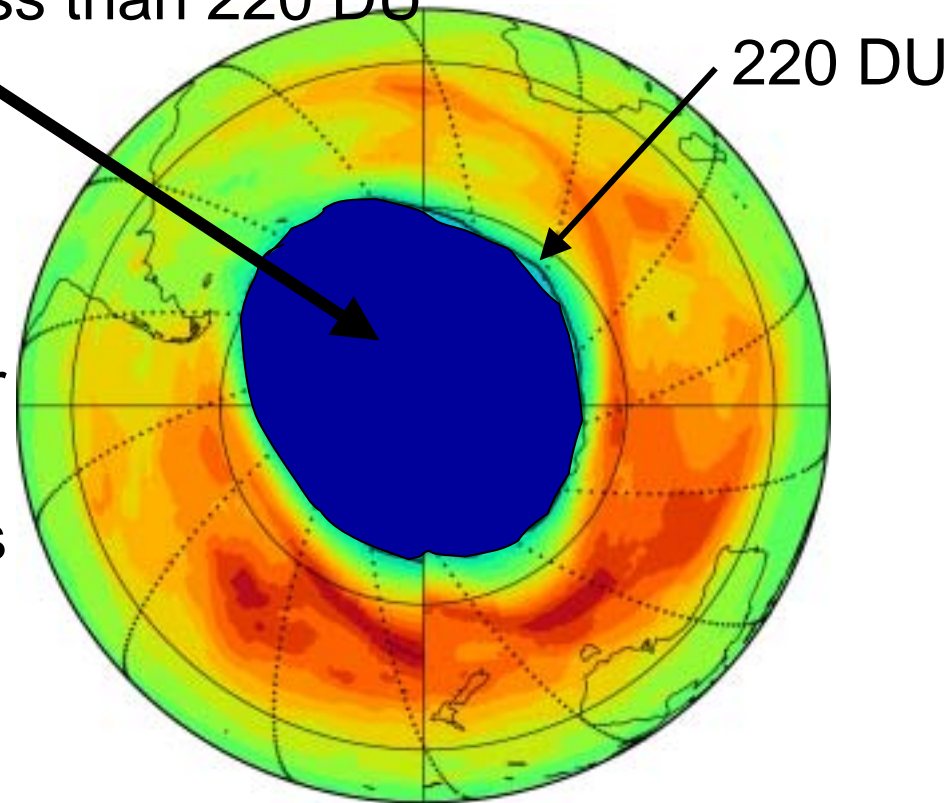
Simple model

GSFC CTM 50-year run

Estimating the ozone hole's size

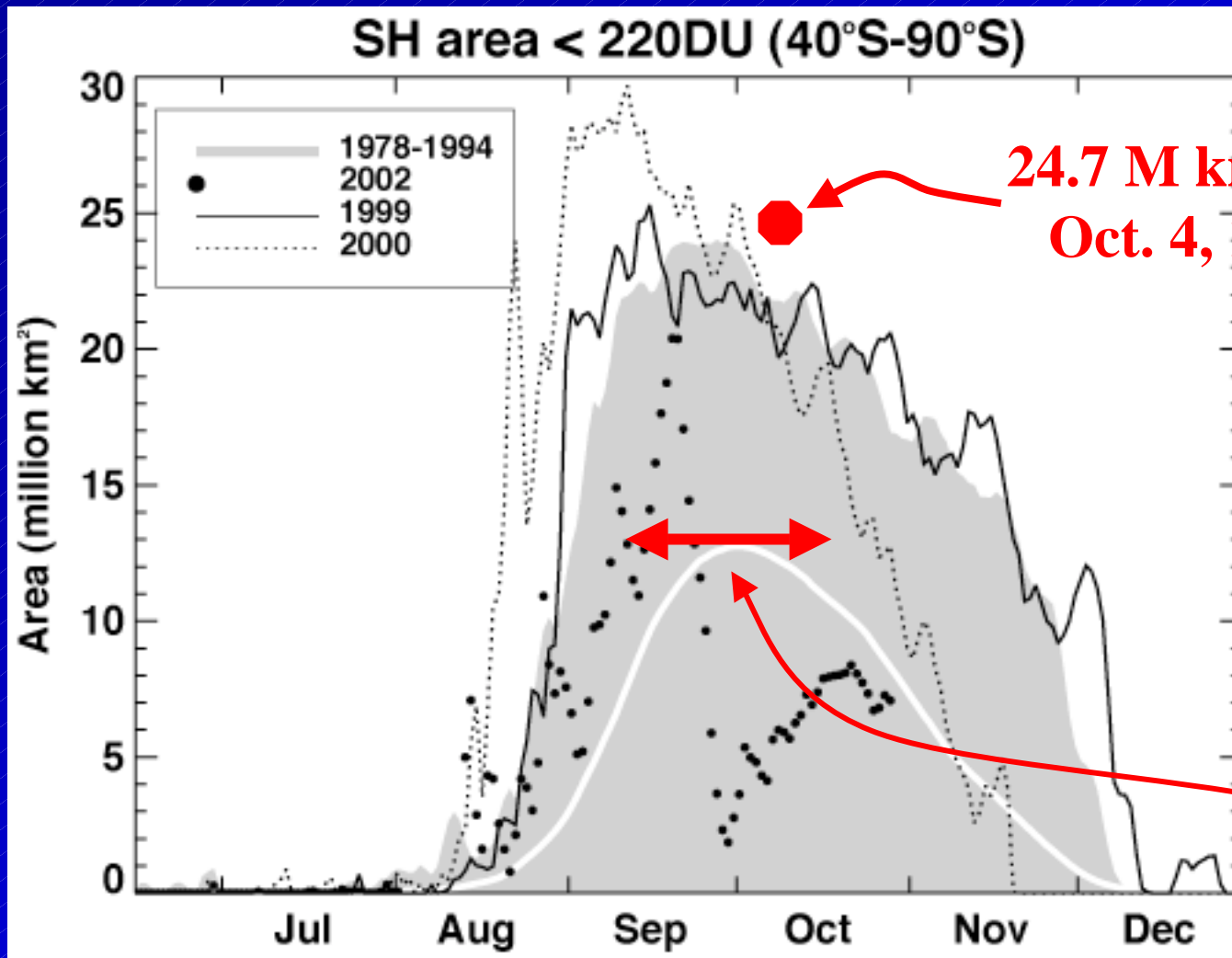
- Ozone hole area is defined by the area coverage of ozone values less than 220 DU

- 220 DU located near strong gradient
- 220 DU is lower than values observed prior to 1979
- Values of 220 tend to appear in early September. TOMS doesn't make measurements in polar night!
- Values of 220 tend to disappear in late November



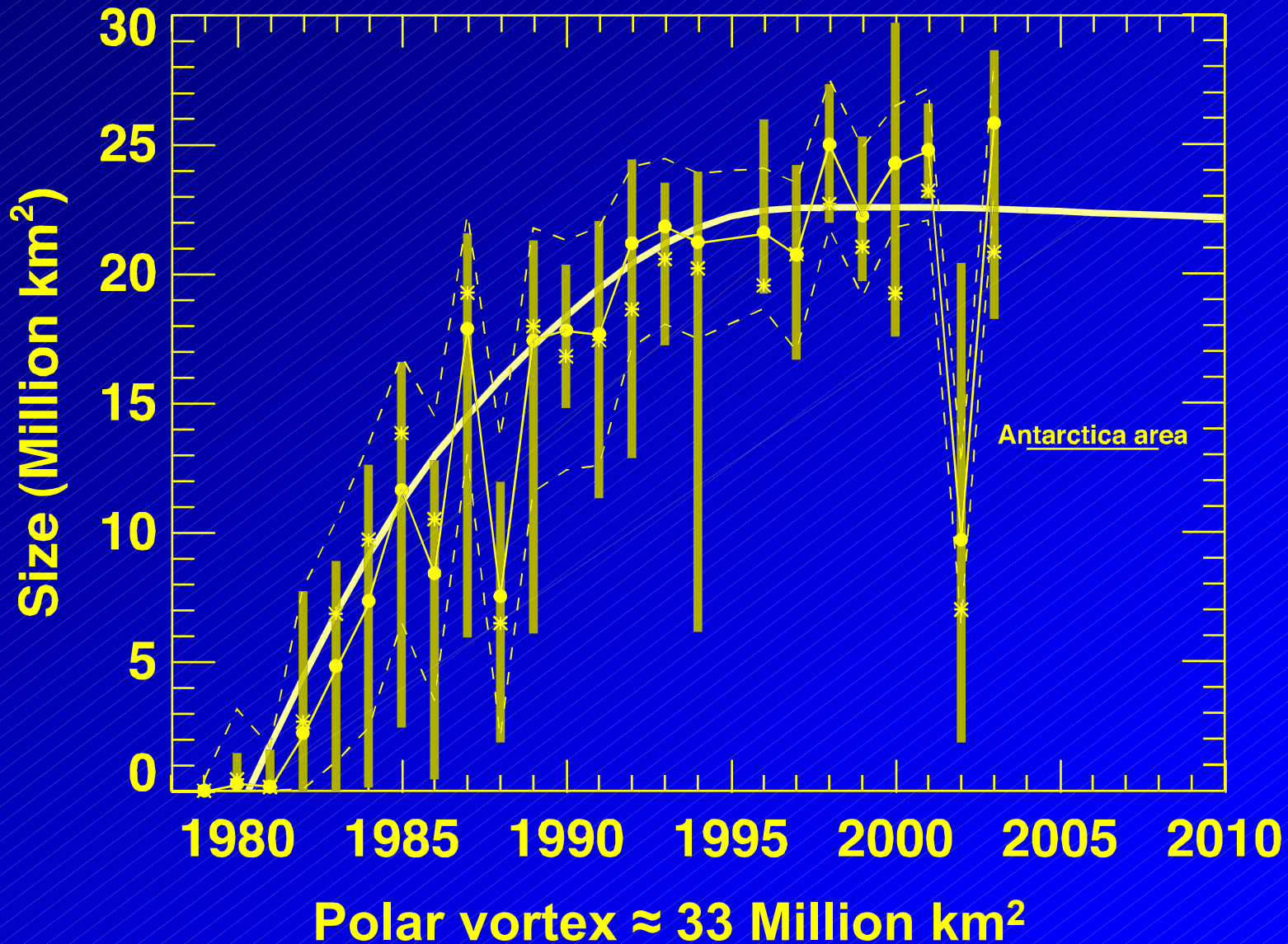
Antarctic Ozone Hole on Oct. 4, 1998

Ozone Hole Area

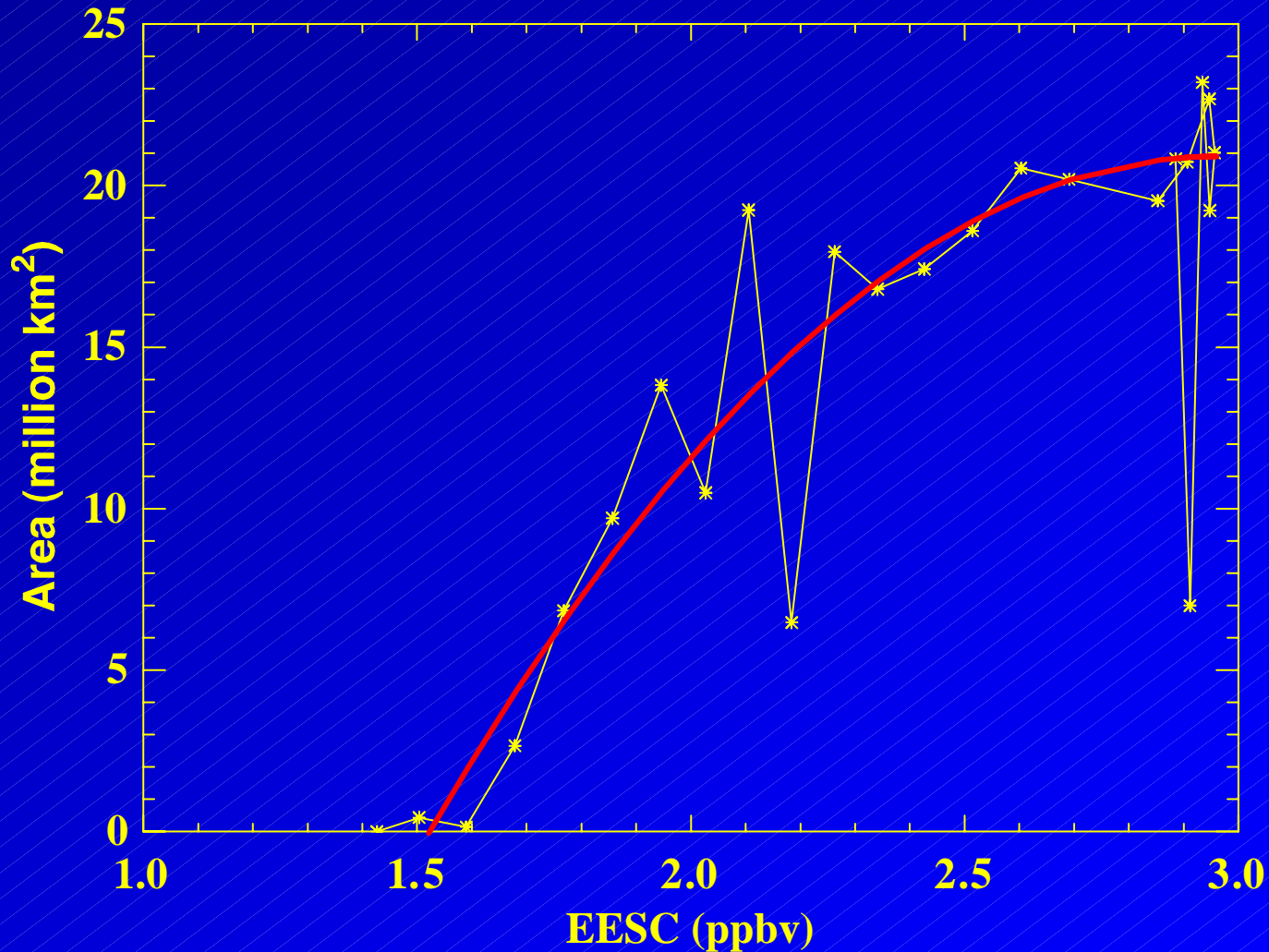


Annual average size estimate derived from an average of September 7 to October 13

Ozone Hole Size Versus Year



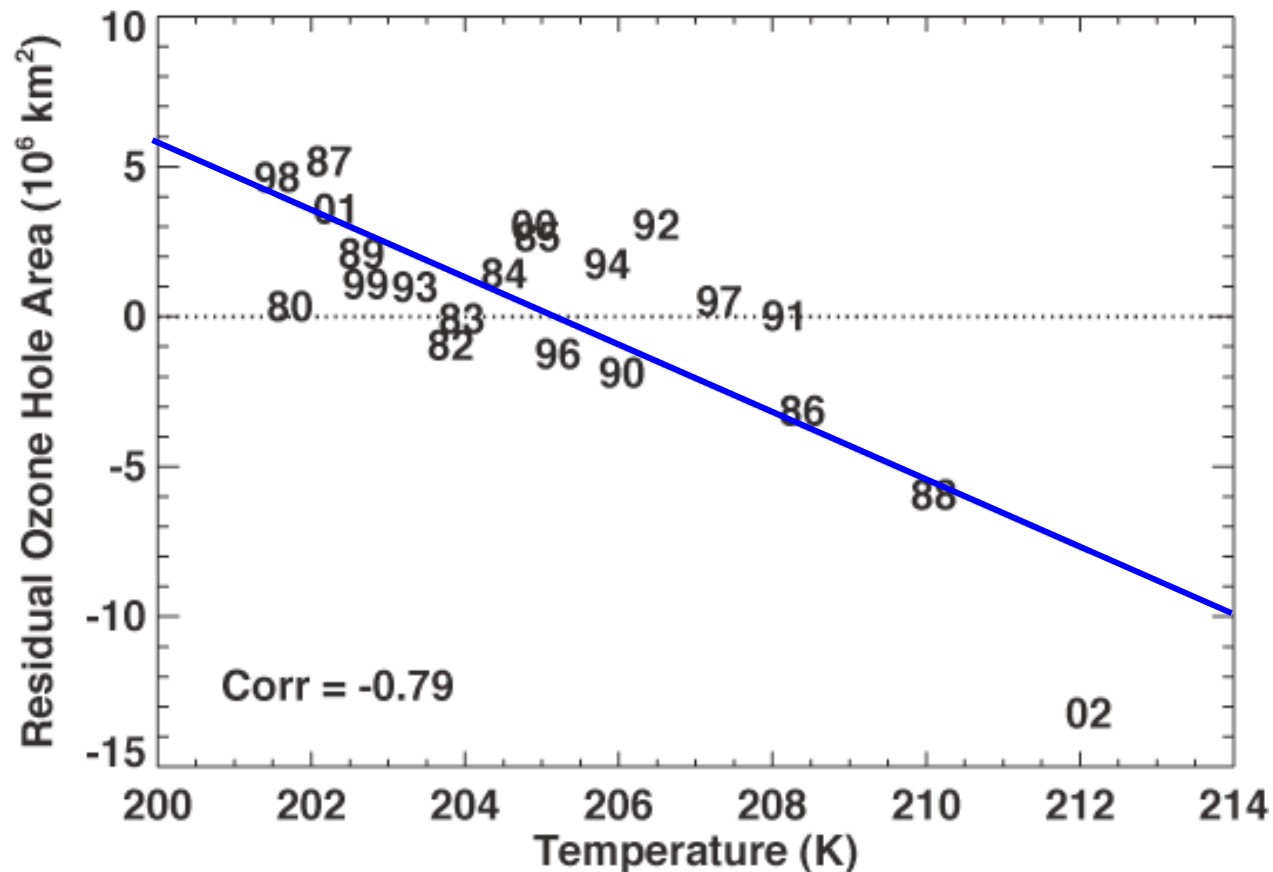
Size vs. EESCI



Quadratic fit of size to EESC



Ozone Hole Residual Area Vs. T

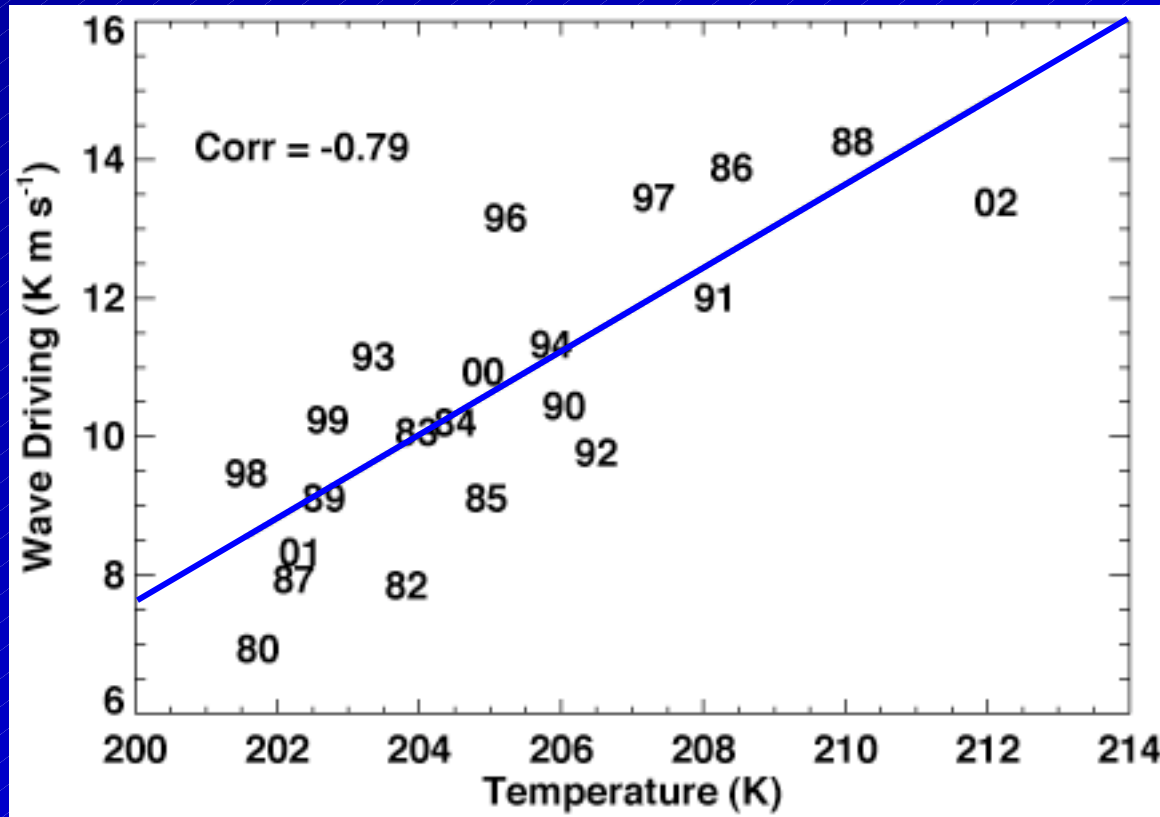


If the temperature is 1 K below normal, then ozone hole's size will be 1.1 Million km^2 larger than normal.

O_3 residual area: 9/21-9/30

T: 9/11 - 9/20, 50 hPa, 55-75°S

Heat flux vs. Temperature

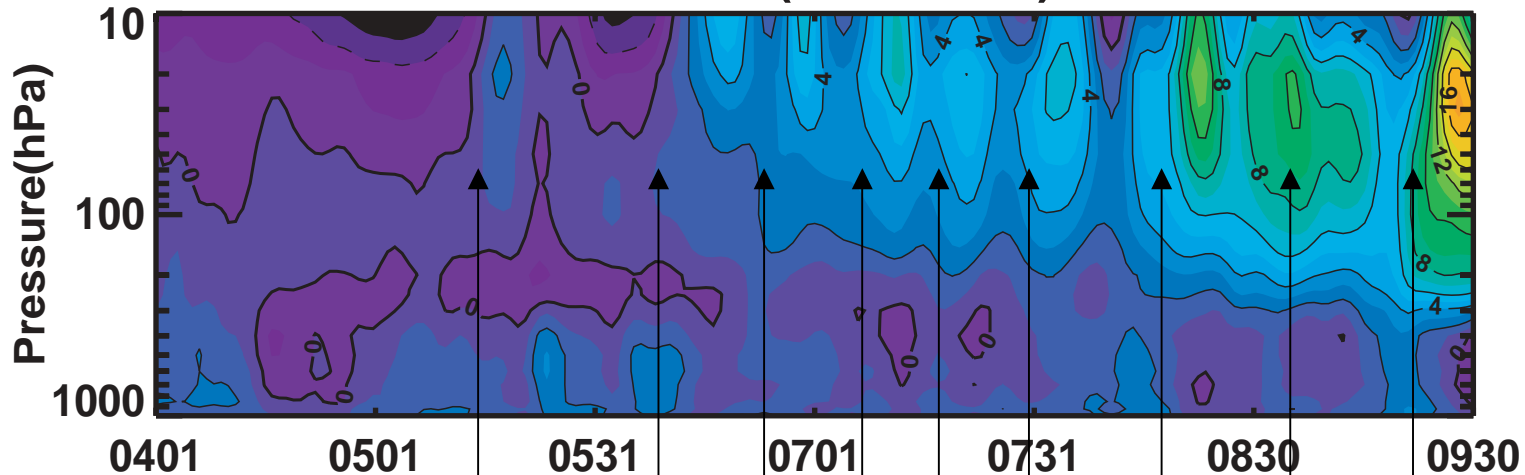


- The higher heat flux of 2002 led to warmer temperatures, while the low heat flux of 1998, 1999, 2000, and 2001 led to colder temperatures. A 10% increase of $-v'T'$ increases T by 1.8 K, and consequently decreases the area by about 2 Million km^2 .

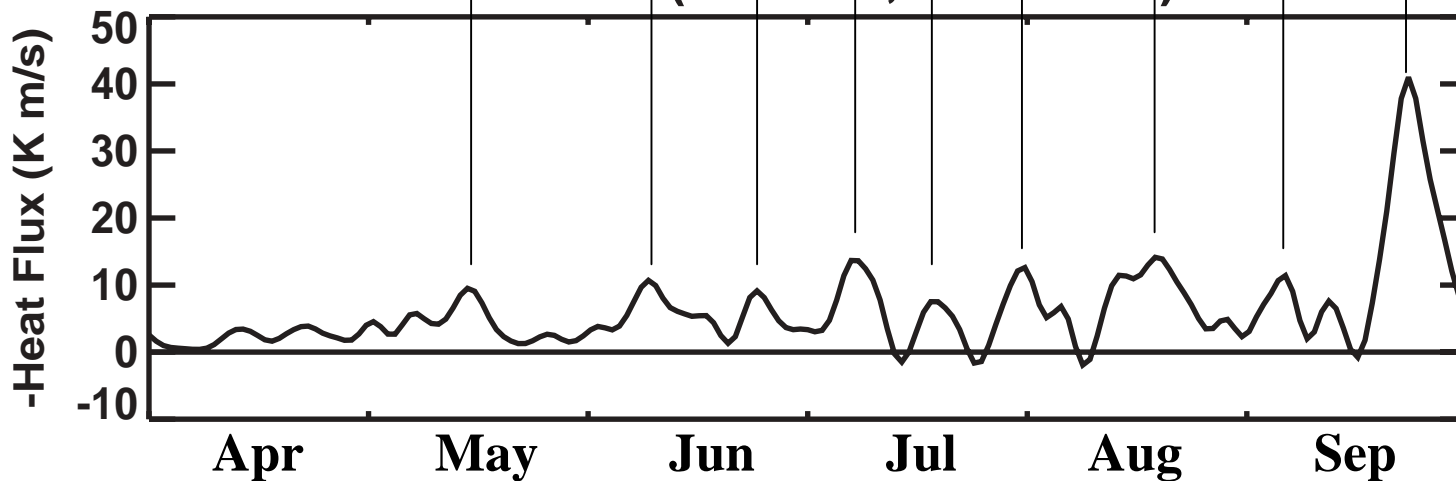


Wave driving & T in 2002

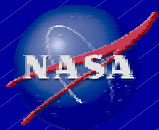
2002 $\overline{T^*}$ (75°S-55°S)



2002 $\overline{v'T'}$ (100 hPa, 40°S-70°S)



A series of wave events warmed the polar collar region, culminating in the major warming of September 22



How do models perform?

3-D Chemical Transport Model (CTM)

- 3-D flux form semi-Lagrangian transport scheme of Lin and Rood (Mon. Wea. Rev. 1996)
- 2.5° longitude x 2° latitudinal horizontal resolution
- 28 vertical levels (about 2 km resolution below 60 hPa and 3.5 km above). sigma-p hybrid scheme with sigma coordinates used below the interface (currently 247 hPa) and pressure coordinates above, to a top at .43 hPa.
- Includes both heterogeneous chemistry & gas-phase chemistry
- tropospheric chemical constituents and reactions are omitted
- 21 transported species and 27 inferred species - 48 constituents.
- 105 chemical reactions

FVGCM: GEOS-4 Configuration

Finite-volume dynamical formulation (Lin 2004):

- Flux-from semi-Lagrangian formulation for horizontal flow
- Material surfaces in vertical formulation
- Remapping to regular hybrid coordinate for calculation of physical tendencies (and chemical reactions)
- Resolution flexible, typically $2.5^\circ \times 2^\circ$ 55 levels, 0–80km

Physical quantities from NCAR CCM3 (Kiehl et al., 1998):

- Radiation transfer due to major and minor gases
- Moist processes, with “diagnostic” cloud water/ice, deep and shallow convection, etc.
- Gravity wave drag: mountain waves and low-resolution spectrum
- Interactive land-surface model

Sea-surface temperature/ice specified from observations:

- Typically AMIP or Hadley Center distributions

A simple model

1. Use trajectory model to simulate the sensitivity of ozone at the vortex edge (Kawa et al., 1997; Schoeberl et al., 1996).

2. $\partial A / \partial t = \partial A / \partial \Omega \cdot \partial \Omega / \partial \chi \cdot \partial \chi / \partial t$

From TOMS

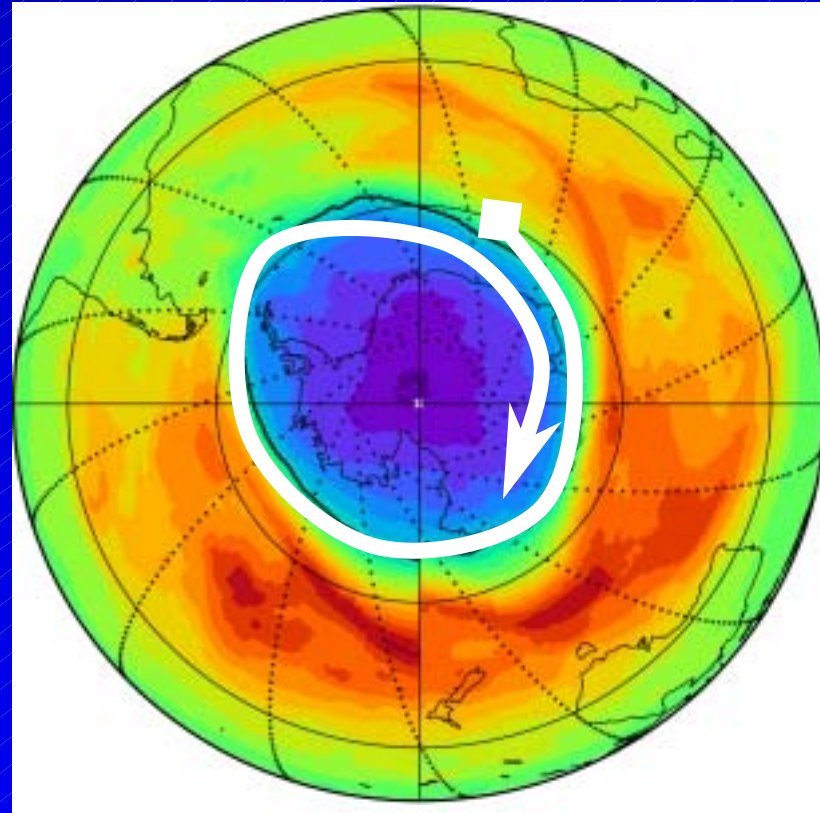
From Sondes

From Model

Temperature sensitivity test

$$\partial A / \partial T \text{ (Obs.)} = -62 \text{ ppbv/K}$$

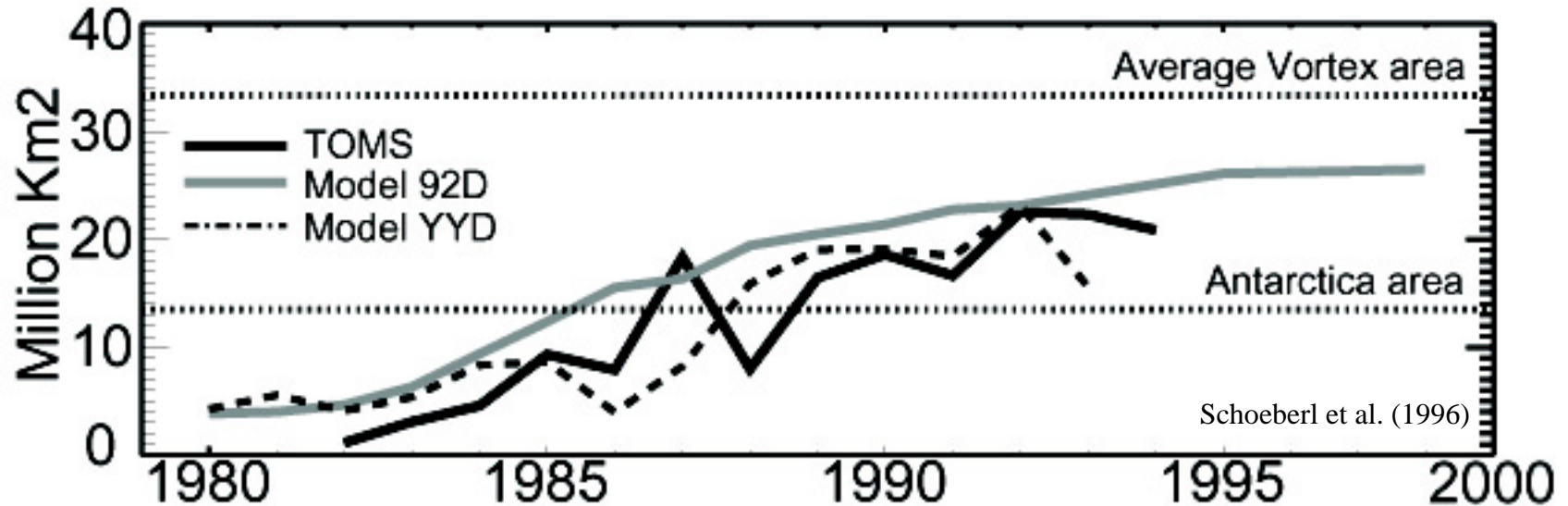
$$\partial A / \partial T \text{ (Mod.)} = -54 \text{ ppbv/K}$$



Results

- $\Delta A = 1 \text{ Million km}^2 = \Delta \bar{T}$ of 1.1 K
- $\Delta A = 1 \text{ Million km}^2 = \Delta \overline{v'T'}$ of 10%
- $\Delta A = 1 \text{ Million km}^2 = \Delta Cl_y$ of 130 pptv
- Since Cl_y is decreasing at a rate of 35 pptv/year \rightarrow ozone hole is decreasing in size by about 0.28 M km²/year
- Current size of 24 M km² \rightarrow 20 M km² in 2016

Background

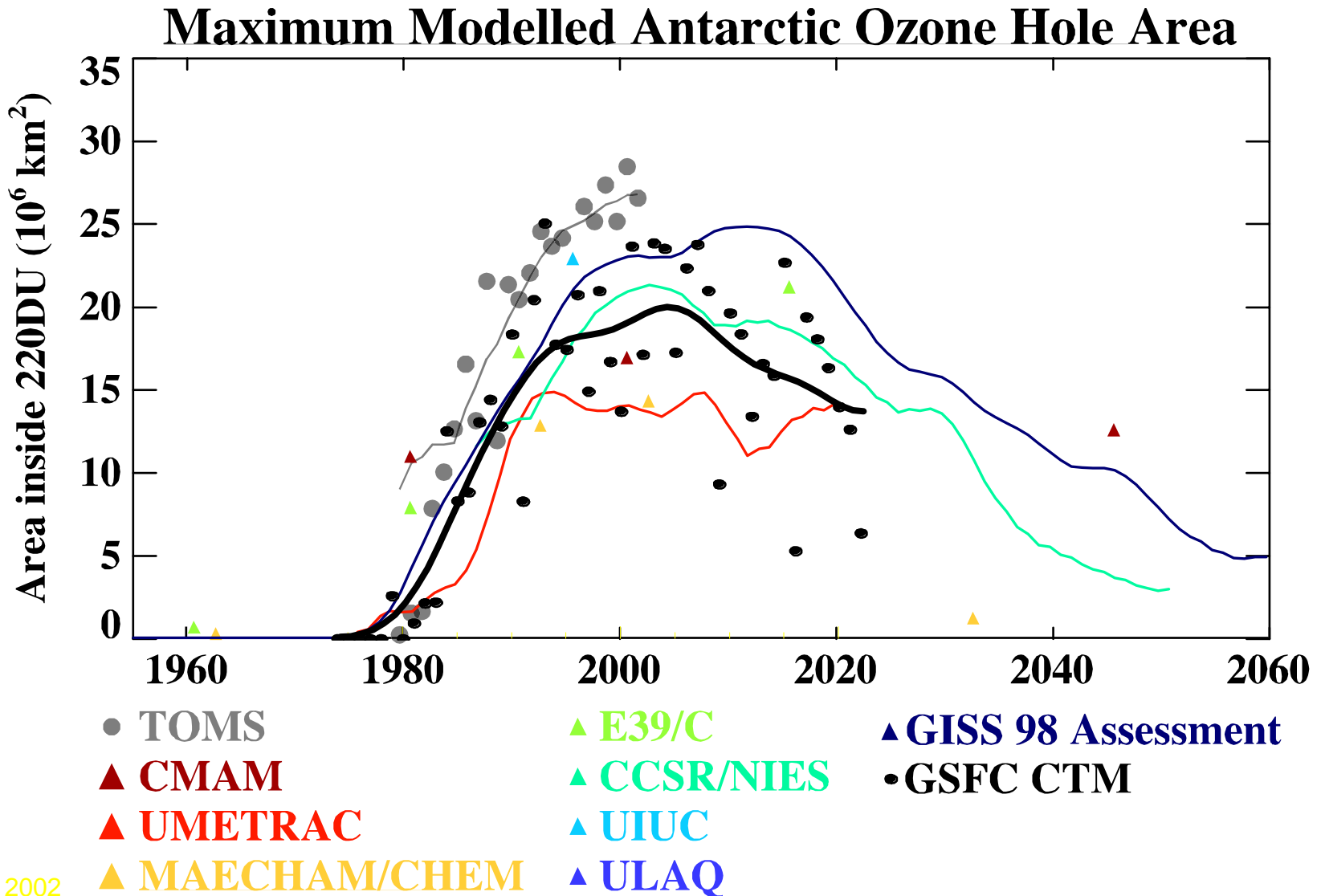


Schoeberl et al. (1996)

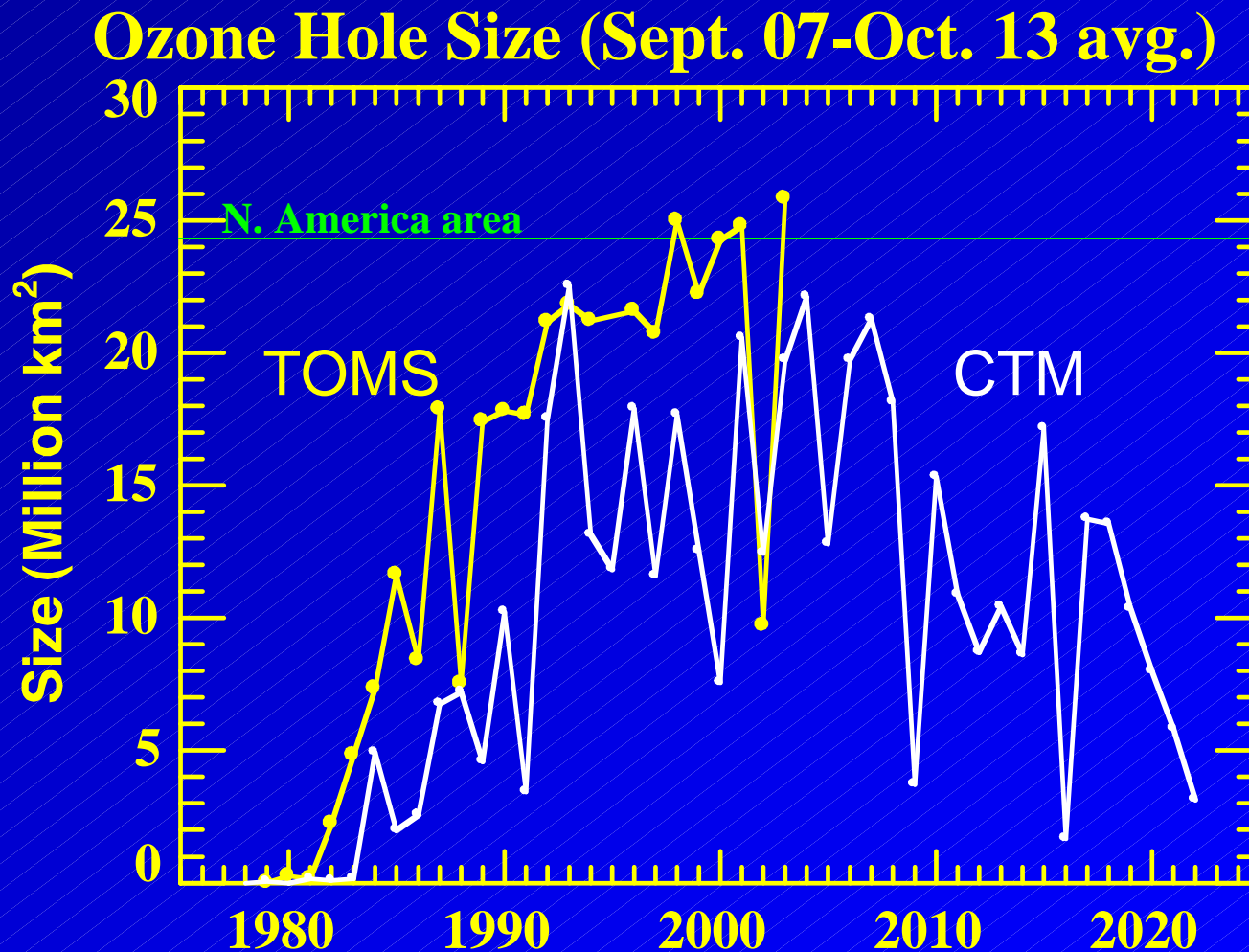
Schoeberl et al. (1996): Figure 10b. Ozone hole size on Sept. 17. Model 1992 dynamics (gray line), Model with year-to-year dynamical variations (dotted line), TOMS (solid black).

Bodeker et al. (2001): 1) Size of the ozone hole has increased since 1979, 2) Size is not related to temperature, and 3) size is not related to vortex size or strength.

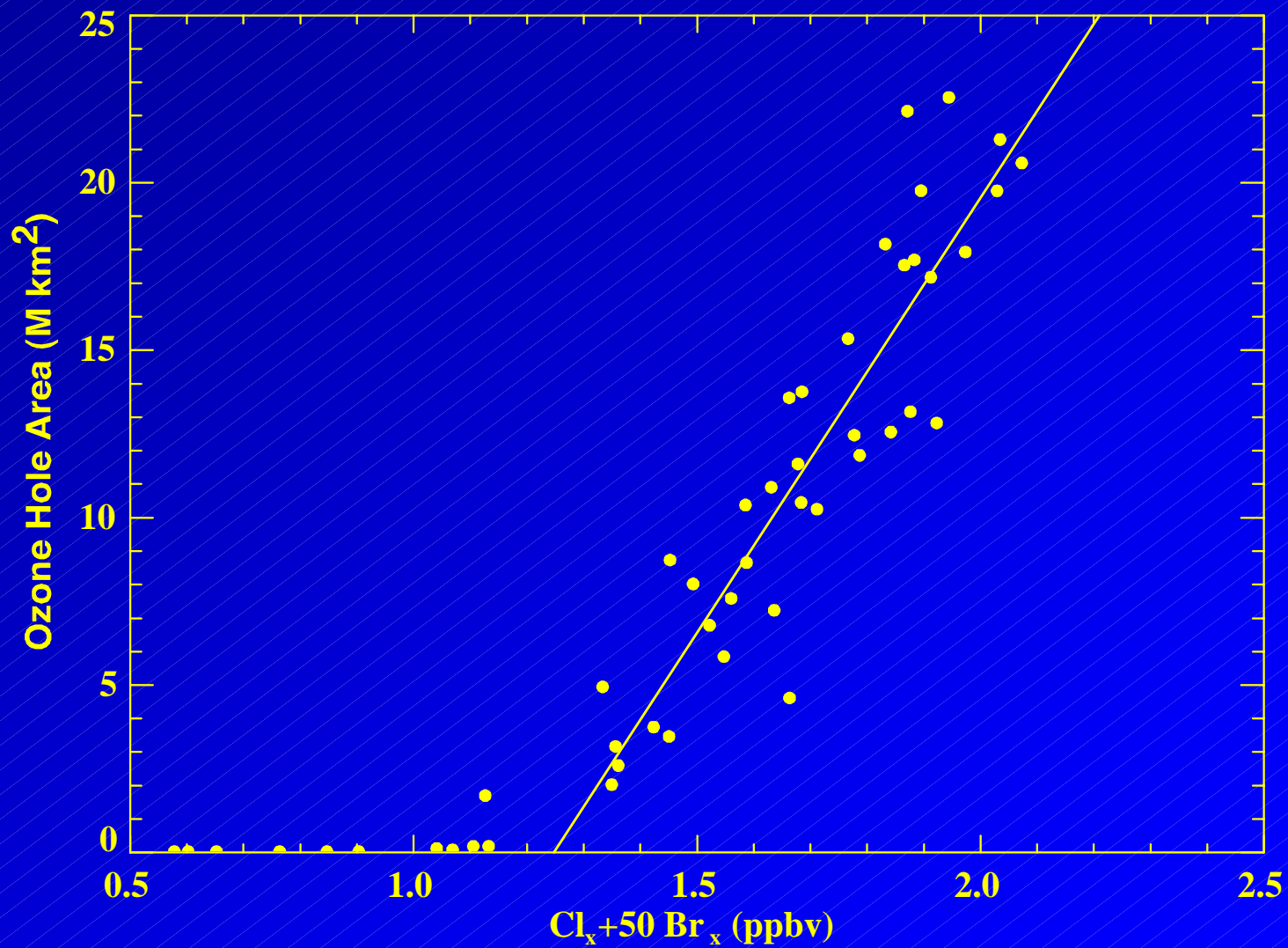
Model size estimates



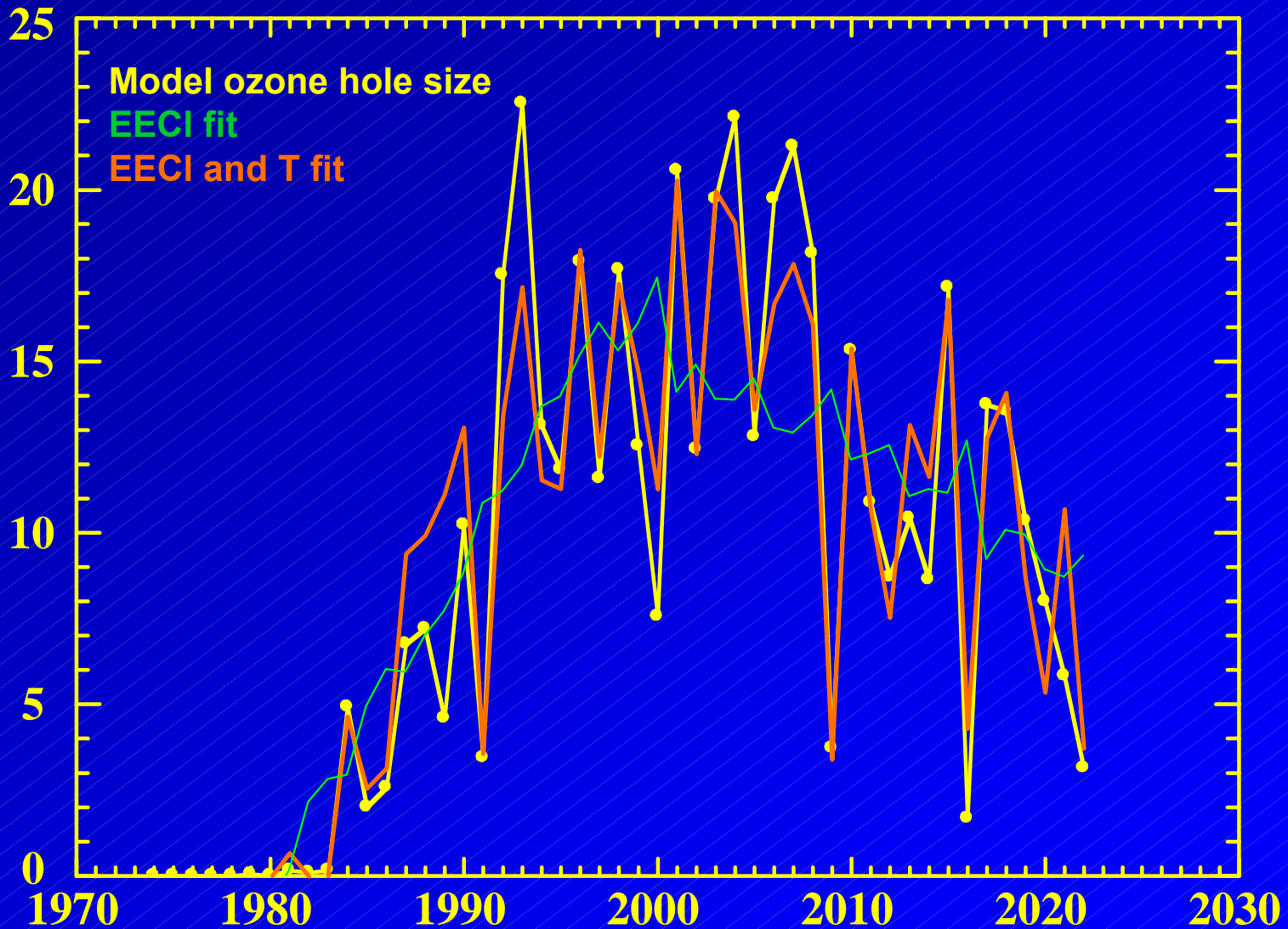
Ozone Hole Size (model & data)



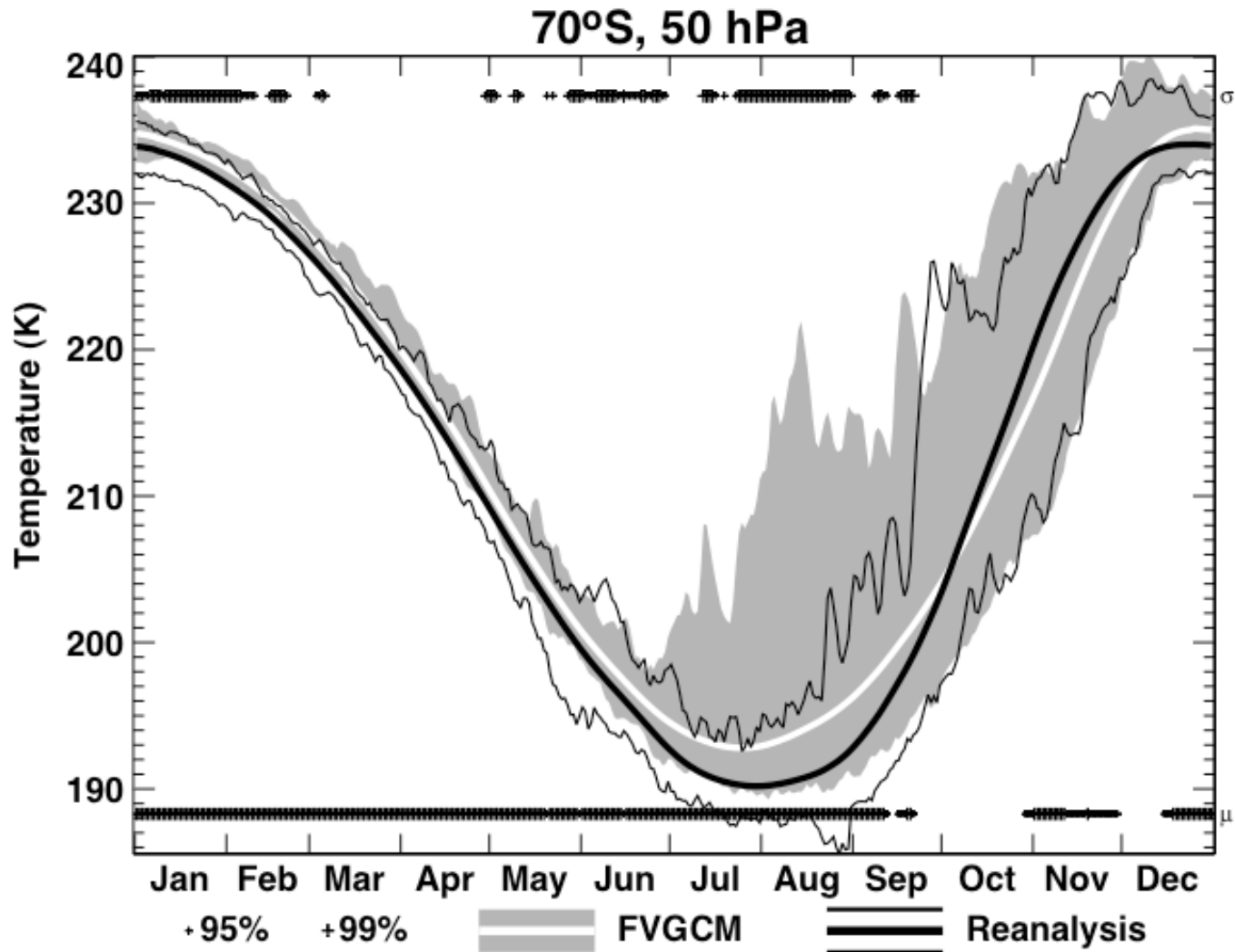
O_3 hole area vs. EECI



O_3 hole model fit



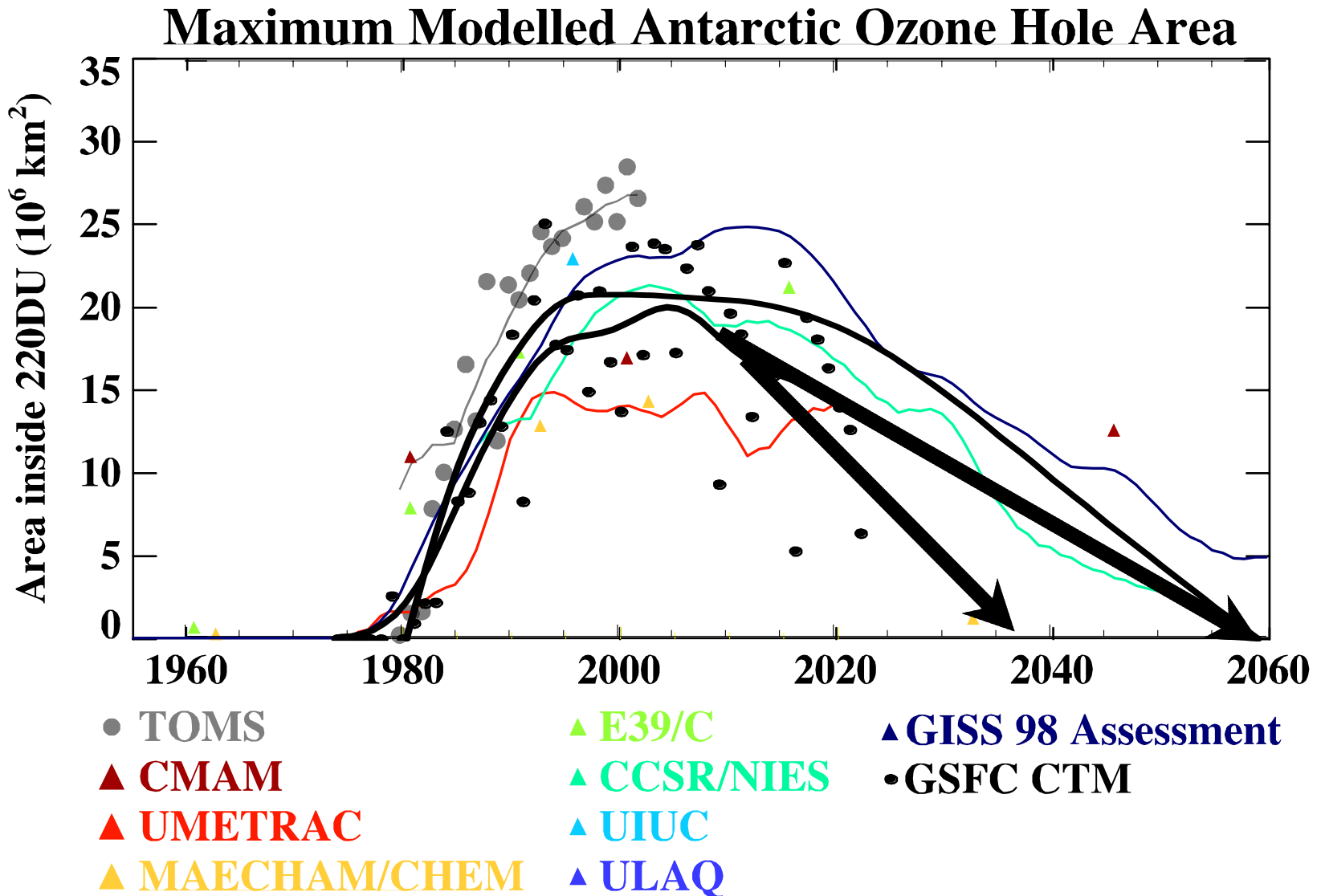
Model Temperature



Model is too warm compared to observations, explains approximately 2-4 M km² of size error

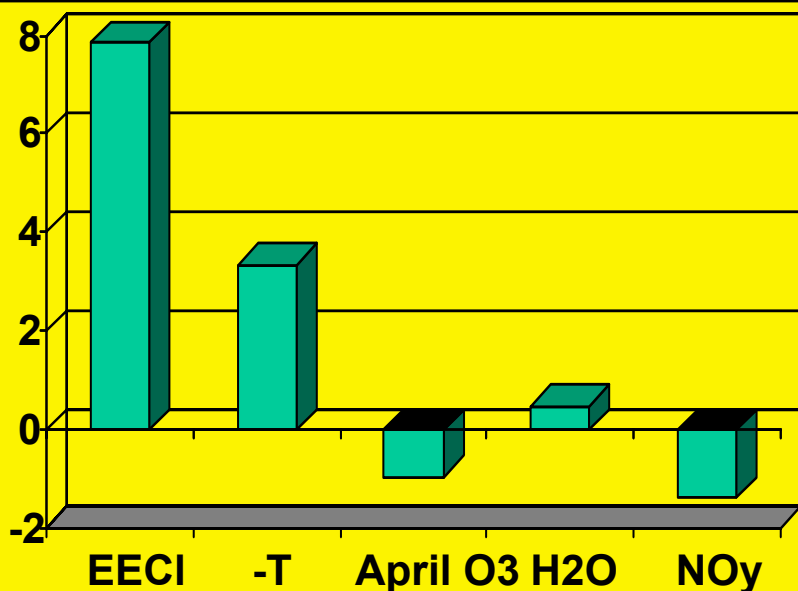


Model size estimates



Factors in the model that control size

■ Variabil



- EECI
- Temperature (colder is a larger hole)
- Initial ozone (low April leads to larger hole)
- Higher water produces a large hole
- Higher total odd nitrogen produces a smaller hole

Summary & Conclusions

- The hole marginally increased during the last few years because of a series of cold winters (1998-2003). Dramatic reduction in 2002.
- Antarctic losses are primarily keyed to Cl_y & Br_y and secondarily keyed to T in the vortex collar. Temperatures are directly tied to the wave tropospheric wave forcing.
- Trajectory modeling & the CTM show reasonable agreement with growth and variability of the hole. Albeit, somewhat of an underestimate
- The predicted recovery is in mid-century. Recovery will be detected in about 2020 or so.
- A 1 K cooling of the Antarctic stratosphere requires an additional decrease of 0.4 ppb of Cl_y which is approximately 14 year delay of the recovery